AD-A039 850 NAVAL SURFACE WEAPONS CENTER WHITE OAK LAB SILVER SP--ETC F/G 9/2
PROGRESS TOWARD THE CROSSTIE MEMORY IV.(U)
OCT 76 L J SCHWEE, W E ANDERSON, H R IRONS
UNCLASSIFIED NSWC/WOL/TR-77-21 NL

1 OF 1
ADA039 850

END
DATE
FILMED
6-77

NSWC/WOL/TR 77-21

NSWC/WOL/TR 77-21

12

NSWC TECHNICAL REPORT

WHITE OAK LABORATORY

PROGRESS TOWARD THE CROSSTIE MEMORY IV

1 OCTOBER 1976

NAVAL SURFACE WEAPONS CENTER
WHITE OAK LABORATORY
SILVER SPRING, MARYLAND 20910

Approved for public release; distribution unlimited

NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MARYLAND 20910

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSWC/WOL/TR-77-21	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Progress Toward The Crosstie Memory IV.		5. TYPE OF REPORT & PERIOD COVERED Interim Report (October 75 to October 76) 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) L. J. Schwee, W. E. Anderson, H. R. Irons O. J. Van Sant, Jr. J. W. McCorkle		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Surface Weapons Center White Oak Laboratory White Oak, Silver Spring, Maryland 20910		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62762N; F54545; WF54545602; WR3121;
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 1 October 1976 13. NUMBER OF PAGES 33p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

9 Interim rept.
Oct 75 - Oct 76

18. SUPPLEMENTARY NOTES

16 F54545
17 WF54545602

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Memory	Neel wall
Thin film memory	Magnetic memory
Crosstie memory	Shift register
Crosstie wall	Magnetic shift register

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is the fourth annual technical report of progress toward the crosstie memory and it emphasizes the work done during the past year. In the crosstie memory, information is stored, propagated and detected in magnetic domain walls of Permalloy films about 370 Å thick. Serrated edges on narrow thin film permalloy strips are used to center a domain wall in each strip and provide stable positions for crossties and Bloch lines. The magnetoresistance effect in the information bearing film is used for detection.

over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

391 596/88

59 cm

150,000

The anticipated performance of the crosstie memory includes a shift rate of 20×10^6 bits/sec, a bit density greater than 1.5×10^5 bits/ cm^2, an operating temperature range from -50°C to 100°C, nonvolatility, low cost and low power consumption.

At this time all the necessary functions associated with the shift registers have been demonstrated and shown to be compatible. Present emphasis is being placed on widening the margins of operation so that a reliable and manufacturable device will result.

20,000,000

NSWC/WOL/TR 77-21 1 October 1976

PROGRESS TOWARD THE CROSSTIE MEMORY IV

The purpose of this report is twofold. First, it is intended to serve as an annual report to the Naval Air Systems Command. Second, it is intended to summarize in one place our present knowledge, techniques, and opinions concerning the Crosstie Memory. This report is not self-contained and for complete understanding previous reports ought to be read. They are NOLTR 73-185, NOLTR 74-176, and NSWC/WOL/TR 75-167. There are also available several papers which are referenced in these reports and which have been presented at the Intermag Conferences and Conferences on Magnetism and Magnetic Materials. These papers can be found in the IEEE Transactions on Magnetics and the AIP Conference Proceedings. A recent invited paper in the November 1976 issue of the IEEE Transactions on Magnetics can serve as a useful summary. A shorter summary appeared in the 1976 McGraw-Hill Yearbook of Science and Technology.

The work reported here was funded by NAVAIR Task No. WF545-545-602-A-360360G 20121.

J. R. Dixon

J. R. DIXON
By direction

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS Cont.

Chapter I

SERRATED STRIPS

Functional Requirements

The serrated strips are intended to serve two functions. First, they are intended to place the domain walls which are used as shift register tracks. Second, they are intended to provide a simple means of propagation. The optimization of the serrated strips therefore consists of finding the best geometry to satisfy the two functional requirements. One of the more successful arrangements to date is shown in Figure 1. Here the film is 370 Å thick and on all the strip widths shown the walls formed nicely as desired. The interior of the same array is shown in Figure 2 for a 600 Å thick film. As expected, crossties form spontaneously at zero field in this thickness range, but they form at locations determined by the strip geometry. All 1536 locations in the array were filled with perfectly placed crossties.

Wall Placement

The ease with which walls are formed depends on the shapes of the serrated strips. The critical parameters are shown in Figure 3. Here the width at the neck is a, the length between denticles is b, the angle θ is the denticle angle, and ϕ is the apex angle. Easiest wall placement has been observed when ϕ is an acute angle as shown in Figure 1 and Figure 2. The field required to place the wall depends also on the width of the strip a. However, once the wall is entered into the strip, the wall centers itself best when a is narrow, for example, 10 μm. Also, if ϕ is about 90°, the wall once placed is tolerant to larger magnetic fields along the length of the strip before it becomes dislodged.

There are two methods that can be used to place the walls in the strips. One is to apply a large static field perpendicular to the strip length. The second method involves applying both a static and alternating field. In our test fixture a static field of 70 Oe maximum is applied using a coil. Then an alternating field is also applied to the coil and then reduced. Then the static field is reduced to zero. The peak amplitude of the alternating field is about 80 Oe maximum. The alternating field shakes the domain configuration in the strips down to the lowest energy configuration which is that of a single Neel wall or crosstie wall as shown in Figure 1 and Figure 2. The fields used to shake out the

unwanted walls are shown graphically in Figure 4. A few hundred cycles of the alternating field is sufficient. The combination of static and alternating fields is the most practical since the fields do not have to be as large as in the case where only a static field is used. On certain strips a 20 Oe field is sufficient. The test fixture described above works well on all the strips tested to date.

It would be nice if the fields used to propagate would also be large enough to set up the walls. Then, once the memory is fabricated, it could be run for a few seconds and the walls would be ready to receive information. This may be a practical approach, but it is not a necessary requirement since a few seconds in a coil can also set up the walls initially. Once the walls are set up, the propagate fields tend to center the walls in the strips. Here we find ourselves in a position where we are trying to optimize two functions with parameters which interact, and the optimum parameters for one function are not necessarily optimum for the other function. Therefore priorities must be set. The possibility that a shake down field external to the device might be needed initially to set up the walls in the film is not considered an unacceptable hardship. Also, if the walls are hard to place, they are hard to take out. So unless the device is subjected to large fields the initial wall setup should serve for the lifetime of the device. Therefore, the parameters should be optimized for propagation with good margins of operation rather than for easiest wall placement.

Two Pulse Propagation with a Single Conductor

A new method of propagation, which is simpler than those previously described, has been found. The pulse sequence is described in Figure 5. Two pulses are needed to shift a bit from one serration to the next. The Bloch line must be moved, then the crosstie must be relocated. This is done by a duplication and annihilation process.

The pulse used to move the Bloch line must be large enough to move the Bloch line out of its potential well but not large enough to nucleate new Bloch line-crosstie pairs where "zeros" are intended to be. Also, the pulse must persist long enough for the Bloch line to move into the next potential well provided by the neighboring serration. The amplitude of the pulse that can be used depends upon the nucleation field, pulse length, thickness of the film and serrated strip geometry. Pulse duration depends upon pulse amplitude, Bloch line mobility, and the distance between serrations. The pulse length normally used is 25 nsec and this depends mostly on the distance b of Figure 3. Such a pulse is shown as a negative pulse in Figure 5 between Step 1 and Step 2. After such a pulse is applied, the Bloch line is found in the next potential well as shown in Step 2 of Figure 5.

The duplication and annihilation pulse is then applied. The pulse used for this operation is generally about 10 nsec long.

The amplitude of the pulse is greater than is needed for nucleation and annihilation. After the pulse is applied, it appears as though the crosstie has moved as shown in Step 4 of Figure 5. Other considerations and experiments indicate that the crosstie really does not move but that the old crosstie is annihilated and a new crosstie appears in the new location. The reasons for this are now given.

If, instead of a 10 nsec pulse, a pulse 1-5 nsec long is used of the same amplitude, a new crosstie-Bloch line pair appears in between the old crosstie-Bloch line pair shown in Step 2 of Figure 5. Nothing happens in other locations along the wall because a positive pulse is being used and the rest of the wall is already positive. Each time the sequence is repeated a new crosstie-Bloch line appears. This is illustrated in Figure 6. Such a phenomenon may have application as a counter or other logic element in conjunction with the crosstie memory. The 1-5 nsec long pulse is again large enough in amplitude for nucleation and annihilation but not long enough in duration for the Bloch line to travel to its neighboring crosstie for annihilation. Bloch line mobility is about 48,000 cm/Oe-sec. The fact that a new crosstie-Bloch line appears when a 1 nsec pulse is used prompts one to expect that about 1 nsec after the application of the 10 nsec pulse used in Figure 5 a new crosstie-Bloch line pair must form.

Now we can consider what happens if a 20 nsec pulse is applied instead of the 10 nsec pulse of Figure 5. Again the pulse is of the same amplitude as the 10 nsec pulse, large enough for nucleation and annihilation. After such a pulse is applied to the situation shown in Step 2 of Figure 5, the crosstie and Bloch line disappear. Here the pulse persisted long enough for both crossties to be annihilated presuming that a new crosstie-Bloch line pair was generated in the first nsec of its application.

With all these considerations it becomes clear that after the first nsec of the 10 nsec pulse a new crosstie-Bloch line must appear between the old crosstie Bloch line pair. The next question to be answered is why the old crosstie becomes annihilated in preference to the new crosstie during the 10 nsec pulse. Here we must consider crosstie bending.

When a quasi static field is applied perpendicular to the wall, the Bloch line first runs to its neighboring crosstie and then as the field increases the crosstie bends. This is illustrated in Figure 7. In Step 1 of Figure 7 no field is applied and in Step 2 a field is applied causing the magnetization to rotate and the crossties to bend. If the field is increased further to cause crosstie annihilation and then removed, the situation shown in Step 3 results.

Now, if we wish to generate crossties, a field must be applied in the direction shown in Step 4. Since a field is present during nucleation, we must surmise that the crossties will enter bent. If the nucleation field persists, the Bloch line moves along the

wall reversing the energetically unfavorable Neel wall until the situation shown in Step 5 results. Step 5 is the same as Step 2 except for polarity reversal. This shows why the crosstie is expected to be bent when it nucleates.

The crossties consist of Neel walls which have coercivity and once bent a return to zero field does not straighten them completely. Experiments with fast rise-time pulses (less than 1 nsec) and variable duration indicate that a pulse of about 7 nsec duration is required to bend an already present straight crosstie. This suggests that the crosstie possesses inertia as magnetic walls do and an acceleration time is required. The acceleration time for the Bloch line is apparently much shorter.

With all these considerations we can now return to Figure 5 and examine Step 3. Within the first nsec of the applied pulse a new crosstie-Bloch line pair enters between the old crosstie-Bloch line pair. The new crosstie enters bent. As the pulse persists, the Bloch lines travel toward their neighboring crossties on the left. The new Bloch line has a shorter distance to travel and arrives at its neighboring crosstie (the old one) sooner than the old Bloch line. The trailing crosstie-Bloch line pairs are annihilated and, before the leading pair can come together, the pulse is shut off. The end result is then shown in Step 4 of Figure 5. The propagation sequence shown in Step 5 has been repeated often and a movie is available showing propagation by this technique. Unfortunately, the pulse length and amplitude needed for consistent operation can be varied over only a few percent on serrations tested to date and the margins of operation are not yet large enough for high reliability by this method. It has been noticed, however, that this propagation technique works best when the distance b of Figure 3 is about 1/2 the distance a of the same figure. This supports the crosstie bending arguments presented above. Experiments to date have also been hampered by the fact that a Bitter solution is required for observation and it interferes with Bloch line motion and changes crosstie coercivity. Further experiments with complete shift registers are required to fully evaluate this propagation technique.

Two Conductor Propagation

Reliability and yield will go hand in hand with large margins of operation in the Crosstie Memory. The propagation scheme described above used a conductor which ran along the serrated strips to provide uniform fields. Propagation was dependent on pulse amplitude and pulse duration. By using two conductors, larger margins of operation are obtainable and pulse duration is no longer critical.

To explain a two conductor scheme of operation it is helpful to make an analogy. The Bloch line and crosstie behave in a magnetic field much as current carrying conductors as shown in Figure 8. Just as a current in a wire produces a circular magnetic field about it which interacts with a uniform field to give rise to the Lorentz force, so also the circulation of the magnetization about a Bloch

line gives rise to a force in a uniform field. The Bloch line and a current carrying conductor can then be considered as circulations in a uniform potential flow with resulting forces. The crosstie can also be considered analogous to a current carrying conductor except that the current is smaller and in the opposite direction from the Bloch line. Also the crosstie has much more friction than the Bloch line, a 2 Oe coercive force compared to 0.1 Oe for the Bloch line.

Previously we described the serrated strip as having potential wells for the crossties and potential wells for the Bloch lines so that the crossties were in stable positions as shown in Figure 1 and Figure 2, and the Bloch lines are in stable positions in between the crosstie positions. We can just as well describe the stable positions in terms of a force field or magnetic field as shown in Figure 9. The equivalent magnetic field which is a function of the strip geometry can be written as

$$H_s = - A \sin \frac{2\pi x}{\ell} \text{ Oe.} \tag{1}$$

Notice that if the Bloch line was moved forward a bit it would be pushed back by the magnetic field so that the positions shown in Figure 9 are stable positions. If the Bloch line and crosstie positions were interchanged, they would be in unstable positions. The value of A can be easily measured by applying a uniform field (down in Figure 9) until the Bloch line jumps to its next stable position. The value of A is then equal to the applied field.

Now suppose that we construct our shift registers in the form of an array as shown in Figure 10. Also above and insulated from the permalloy we etch a meander line through which we will pass current. Not shown in the figure is a microstrip which runs beneath the array along the length of the serrated strips. The vertical component of the magnetic field produced by the meander line is also shown in Figure 10. It can be described by the equation

$$H_m = B \sin \frac{\pi x}{\ell} \text{ Oe,} \tag{2}$$

while the field produced by the microstrip is a constant

$$H_u = C \text{ Oe.} \tag{3}$$

Now suppose we have an array as shown in Figure 10 and by applying uniform magnetic fields we find that the field necessary to overcome the equivalent serrated strip field is 2 Oe. We also must apply a field of 5 Oe to nucleate crossties, and a 12 Oe field to annihilate them. Now we can place values on H_m and H_u for propagation. A combination of values that will work is given in Figure 11 for moving the Bloch line. The total effective field $H_t = H_s + H_m + H_u$ is plotted in Figure 11 and the movement of the Bloch line to its new stable position is indicated. The applied fields H_m and H_u, of course, cannot exceed the crosstie nucleation field of 5 Oe or "ones" will appear where "zeros" are intended to be. The maximum sum of H_m and H_u is 4 Oe in this example. The

fields must persist long enough for the Bloch line to travel to its new stable position but they may persist indefinitely longer. The travel time for the Bloch line can be estimated by the equation

$$t = \ell/\mu \bar{H}$$

where ℓ is the length traveled by the Bloch line, μ is the mobility (48,000 cm/Oe-sec) and $\bar{H}$ is the average field given by

$$\bar{H} = \frac{1}{\ell} \int_{.5\ell}^{1.5\ell} H_t \, dx. \quad (5)$$

For the values given in Figure 11,

$$\bar{H} = 2 \text{ Oe}. \quad (6)$$

If ℓ is taken as 10 μm, then

$$t = \ell/\mu\bar{H} = 10 \times 10^{-4}/48{,}000 \times 2 \text{ sec} = 10 \text{ nsec}. \quad (7)$$

The 10 nsec travel time given above was derived using magnetic field values measured external to the serrated strip. The actual fields felt by the walls inside the strip are lower because of the demagnetizing fields of the strip. The mobility value used in the calculation above was obtained by observing the Bloch line in an unetched film where the demagnetizing fields were zero. The actual transit time for the conditions described above would be about 25 nsec. However, for such short duration times, the nucleation field is much higher than the static values given in the example and the application of larger field values could bring the travel time close to 10 nsec. The application of uniform fields 25 nsec long will move the Bloch line one serration when the serrations are 12.5 μm apart without nucleating spurious crossties and this is an experimental result using a Bitter solution for observation. Also a 100 nsec pulse of the same amplitude can move the Bloch line 4 serrations. The Bitter solution supplies its own magnetic field which tends to slow down the Bloch line and sometimes even return it to its original position after the pulse is turned off. Hard conclusions on Bloch line mobility cannot be made using Bitter solution observation techniques.

The next step in propagation is the crosstie relocation pulse. This is described in Figure 12. The fields applied for the crosstie nucleation and annihilation step are in the same direction as the wall where "zeros" are present. Therefore, we can apply large fields without fear of nucleating spurious "ones." The field must be large enough for crosstie annihilation. If a value of 14 Oe is used for H_m and H_u and combined with the serrated strip equivalent field, the total field present at the serrations is shown in Figure 12. As this field is applied, first the nucleation field is exceeded and in the direction where a new crosstie-Bloch line will form. Once nucleated, the Bloch line will move rapidly to the left toward the old crosstie. The crossties will move also with such a large

field present. Once the field exceeds the annihilation field, the trailing crosstie-Bloch line pair is annihilated. The new crosstie will move toward its stable position but, because of its coercivity, it will stop before it reaches the zero field point close to its stable position when the applied fields are turned off. The time required for this operation is about 10 nsec. Notice also that the lead Bloch line remains in a stable position during the application of these fields and, therefore, will not join and annihilate the new crosstie.

The pulse sequence needed for the two conductor propagation scheme is illustrated in Figure 13. The sequence shown will move a bit two serrations or one period in the shift register.

There are alternative methods of achieving the fields described above and other methods may eventually prove to be superior to the meander line technique.

Chapter II

EASY AXIS, HARD AXIS, NO AXIS

Easy Axis

The crosstie wall in an unetched film runs along the easy axis or at some small angle to it. Walls which form along the hard axis are zig-zag or sawtooth type walls. Therefore it has been considered in the past to be necessary to run the shift registers along the easy axis of the film. Of course, the easy axis could be made circular so that shift registers could be fabricated in concentric circles or in spiral form. But recent experiments with serrated strips have shown that the shape anisotrophy of the strips is much larger than film anisotropy. Therefore the possibility of walls forming along the hard axis was investigated. It was thought that the likelihood of this succeeding may be small because of previous experiments which showed the occurrence of one dimensional bubbles or tiny reversal domains[1] when strips lie parallel to the hard axis.

Nevertheless, the experiment was performed and it was found that indeed crosstie walls could be formed along the hard axis.

Hard Axis

Crosstie walls formed in serrated strips parallel to the hard axis are shown in Figure 14. The crosstie walls were formed after the application of the wall placement fields along the easy axis. The serrated strips on the edges of the array had a combination of crosstie walls and one dimensional magnetic bubbles. If a field was applied along the hard axis, parallel to the strips, and then removed, one dimensional magnetic bubbles appeared. To form crosstie walls in serrated strips parallel to the hard axis it helps to have the serrated strips close together as shown.

The crossties have a slightly different appearance in that the Bitter solution does not become thinned out near the strip edges. In other words, the magnetization does not become as parallel to the strip along the edges as it does when the strip is along the easy axis. With serrated strips along the hard axis less rotation takes place in the core of the wall and a larger signal can be expected from a NSWC type detector. Also the crossties bend more when small magnetic fields are applied. This is illustrated in Figure 15 where small fields were applied in opposite directions in

1. L. J. Schwee, AIP Conf. Proc. 10, 378-382 (1973)

each photo. The crossties are more strongly pinned along the strip edges and move more along the main wall in the center of the strip than in the easy axis case when fields are applied. Thus there may also be an advantage for larger margins of operation in this direction for the single conductor propagation scheme.

It was possible to form walls in strips oriented at a 45° angle from the easy axis but only when the wall placement field was oriented at an angle which was not quite perpendicular to the strips. When the wall polarity was reversed the wall jumped to the edge of the strip.

The fact that crossties can be formed in strips parallel to the hard axis suggests that no film anisotropy is really necessary. Consequently, isotropic films were deposited by rotating the magnetic field during deposition.

No Axis

Serrated strips were etched at arbitrary angles on isotropic films with the results shown in Figure 16. This shows that there is no problem turning corners and therefore masks have been programed to test the radius of curvature that can be tolerated for meandering serrated strips.

The fact that isotropic films can be used now allows for very long registers to be used and for their turning back on themselves so that a true NDRO memory can be built. It also points up the fact that only the shape of the strip need determine the crosstie-Bloch line properties, independent of film anisotropy.

Ideal Material

A new freedom in the choice of materials results from the use of serrated strips. The material can now be optimized for higher temperature operation and higher magnetoresistance. The addition of cobalt will raise the magnetoresistance effect and gold can increase the thermal stability of the films. The material requirements still include zero magnetostriction and saturation magnetization in the neighborhood of 10,000 gauss.

Chapter III

MAGNETORESISTANCE DETECTION

Fabrication

The theory of operation of the magnetoresistance detector was described in previous reports, but the fabrication of the detector presented many problems. The detector requires that vias in an insulating film be opened so that contact can be made to the permalloy. This is shown in Figure 17. When glass is used as a substrate, a straightforward etching of the vias in SiO_2 is not possible because the etchant penetrates the Ni-Fe, attacks the glass substrate, and floats the Ni-Fe free. This straightforward technique can be used, however, when silicon is the substrate material. When glass is used as the substrate, thick posts are photolithographically defined in the areas to become vias. The dielectric deposition is then completed and the substrate immersed in a reagent to attack the post material.

Initial attempts to fabricate the detectors using negative resists were unsuccessful because the stripper attacked the Ni-Fe. Other techniques using oxidizing, reducing, and neutral plasmas also proved unsuccessful on deposited Ni-Fe films. The reducing plasmas did work well however on sputtered Ni-Fe. It was finally found that the lift off technique using a positive resist (AZ-1350 by Shipley) provides satisfactory vias in the SiO_2. The resist posts are thicker by a factor of two than the SiO_2 and the caps must be swabbed off. A sequence of ketones and Shipley stripper are used to attack the resist posts.

Testing Procedures

The detector shown in Figure 17 was fabricated on a very short serrated strip because the head and tail of the strip secure the domain wall in a positive manner. Thus we could be sure that a wall was present in the desired location. An uncoated Ni-Fe film was etched using the serrated strip pattern shown in Figure 17 and the wall behavior was observed using a Bitter solution. After a field was applied to form the wall, it was reversed and a crosstie appeared at the tail as expected. Upon nucleation of the crosstie the associated Bloch line ran along the strip to the head of the strip. When the field was reversed again, the Bloch line ran toward the tail and the crosstie. The field was increased until annihilation resulted, then the cycle was repeated. Since the NSWC detector

senses the difference between a positive or negative Neel wall, each time the Bloch line passes the detector a voltage change can be expected. The output voltage from the detector resulting from the field reversals described above was expected to form a hysteresis curve as a function of applied magnetic field.

The completed detector was placed in a Helmholtz Coil and a combination of 60 H_z alternating current and direct current was applied so that the field reversal described above could be simulated. The applied magnetic fields were displayed on an oscilloscope on the X-axis and the detector output on the Y-axis. The result is shown in Figure 18. Starting in the upper right hand of the curve the only possible wall configuration is a positive Neel wall. As the field is reduced it continues to be a positive Neel wall until the field is reversed in polarity and a crosstie-Bloch line pair are generated at the tail. Immediately the Bloch line races toward the head of the strip changing the Neel wall to a negative Neel wall. This happens at about -2.5 Oe and is the nucleation field for the crosstie at the tail of the strip. Other crossties nucleate at a higher field. The jump in voltage then is seen as the Bloch line moves past the detector. As the field reverses and becomes positive, the Bloch line moves from head to tail at about 1.5 Oe. This shows up as the jump in voltage at 1.5 Oe. This detector was tested at less than the maximum current that is considered tolerable.

This testing procedure is convenient to evaluate detector configurations and fabrication procedures. One detector has been running for 4 months at a current density of 1×10^6 amps/cm^2 and no evidence of ion migration has yet been seen.

Now that all the functions of the memory have been demonstrated, emphasis will be placed on the fabrication and testing of shift registers.

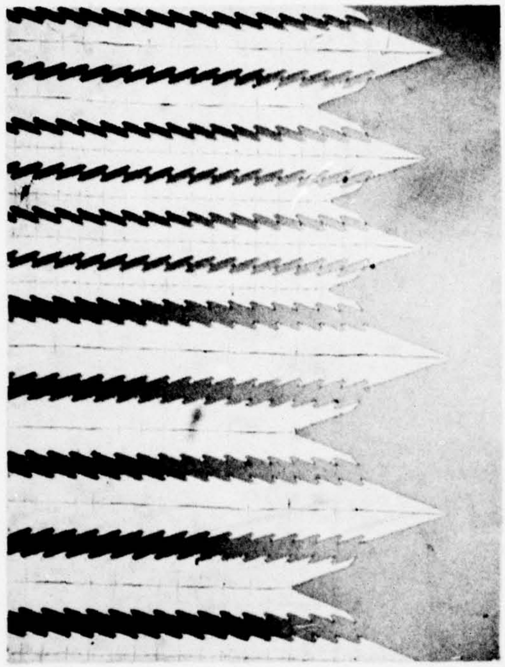


FIG. 1 WALLS PLACED IN 370 Å THICK FILM

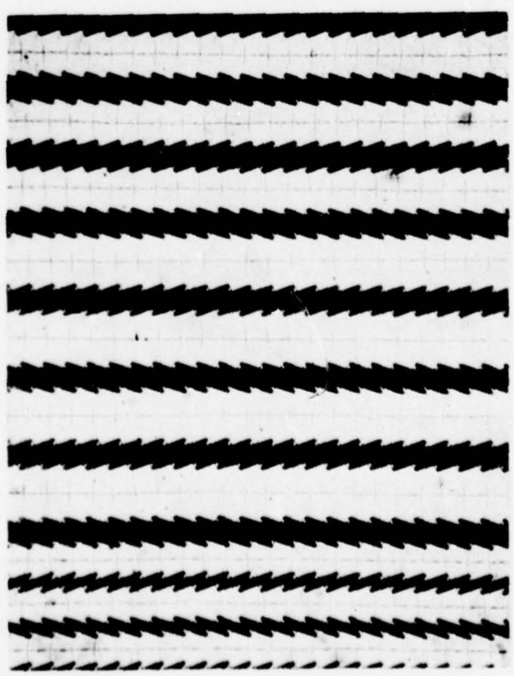


FIG. 2 WALLS PLACED IN 600 Å THICK FILM

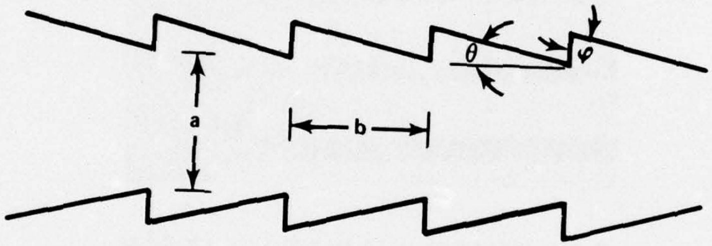


FIG. 3 PARAMETERS USED TO SPECIFY SERRATED STRIP GEOMETRY

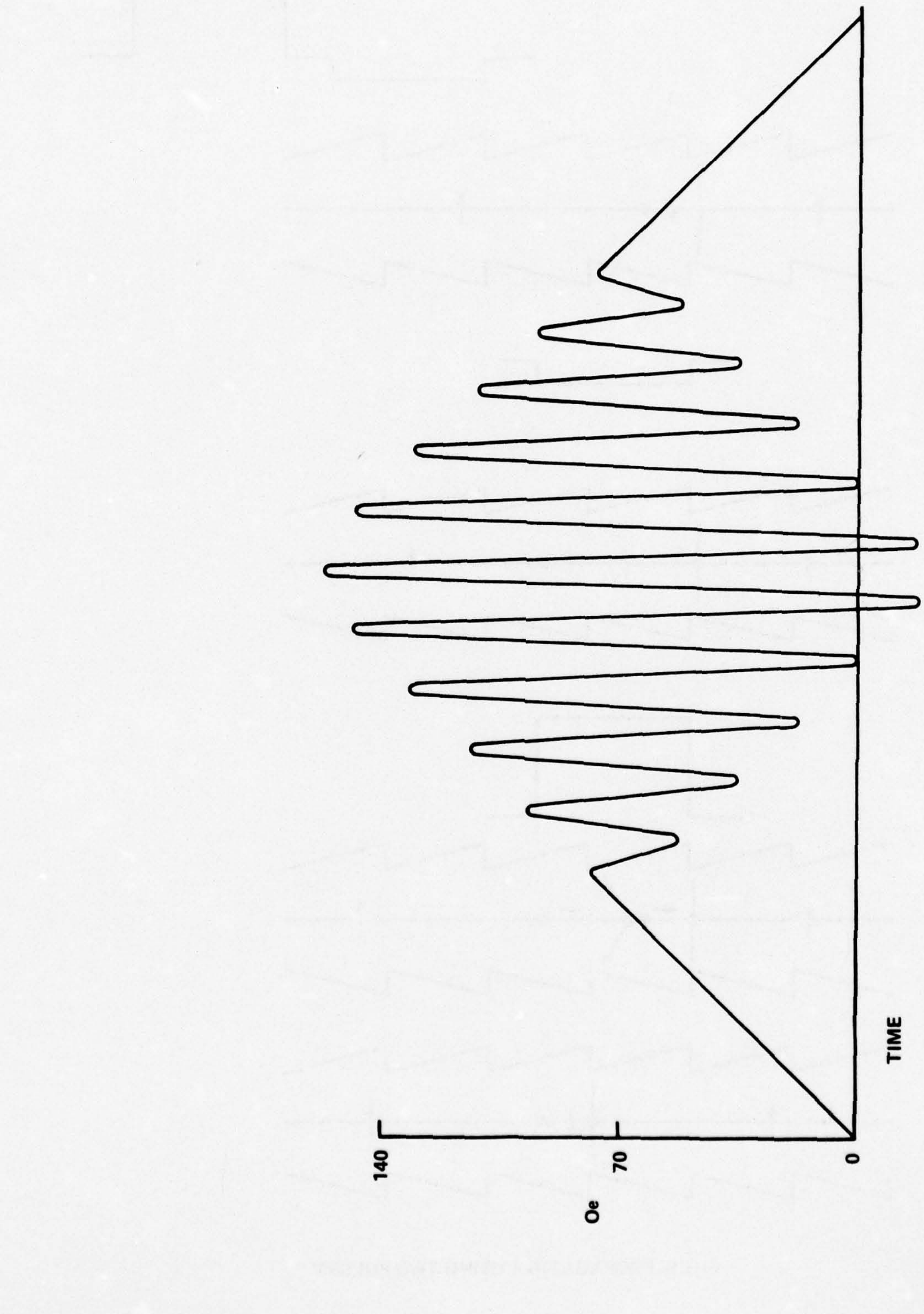


FIG. 4 FIELDS USED TO PLACE WALLS IN STRIPS

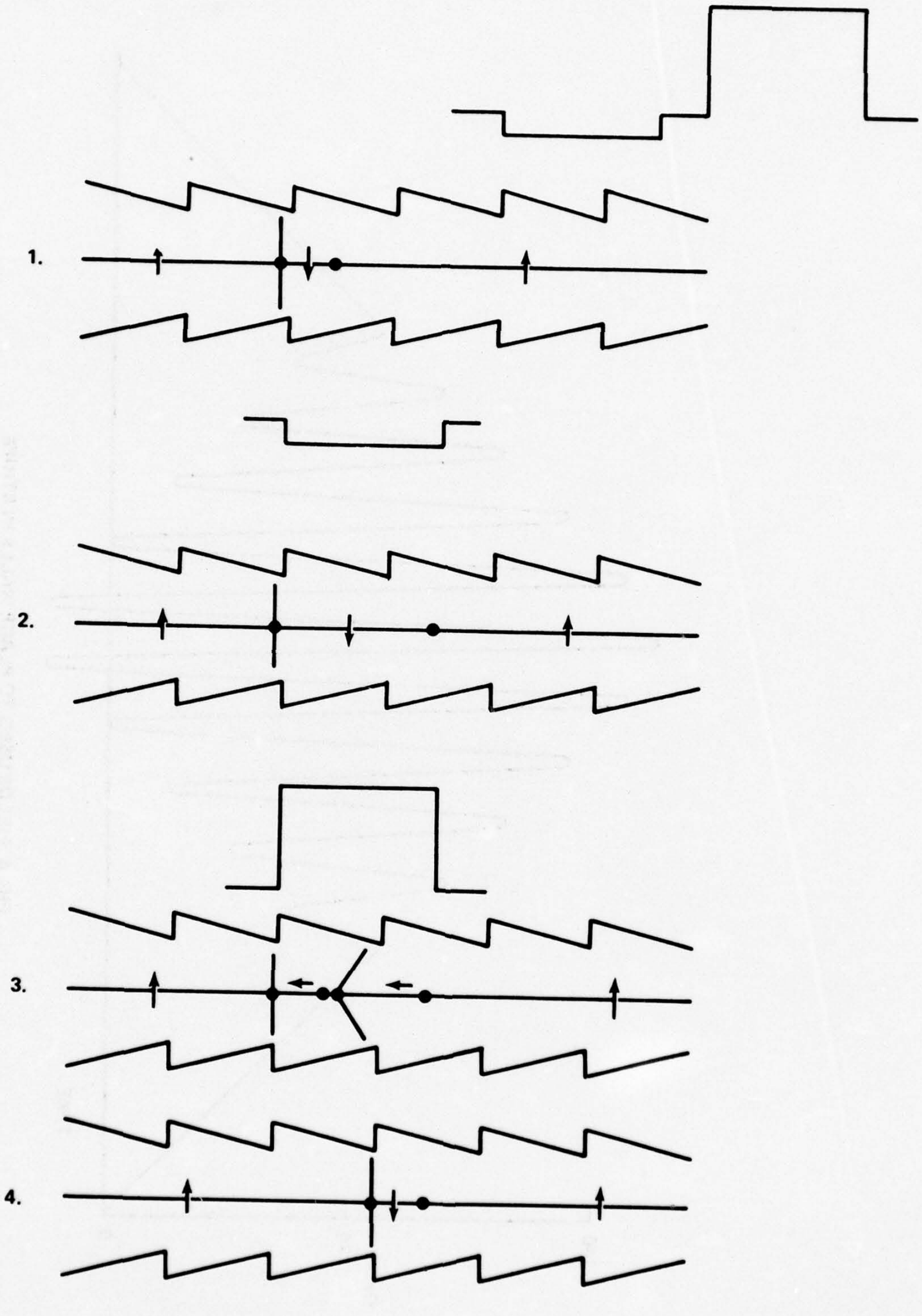


FIG. 5 PROPAGATION USING TWO PULSES

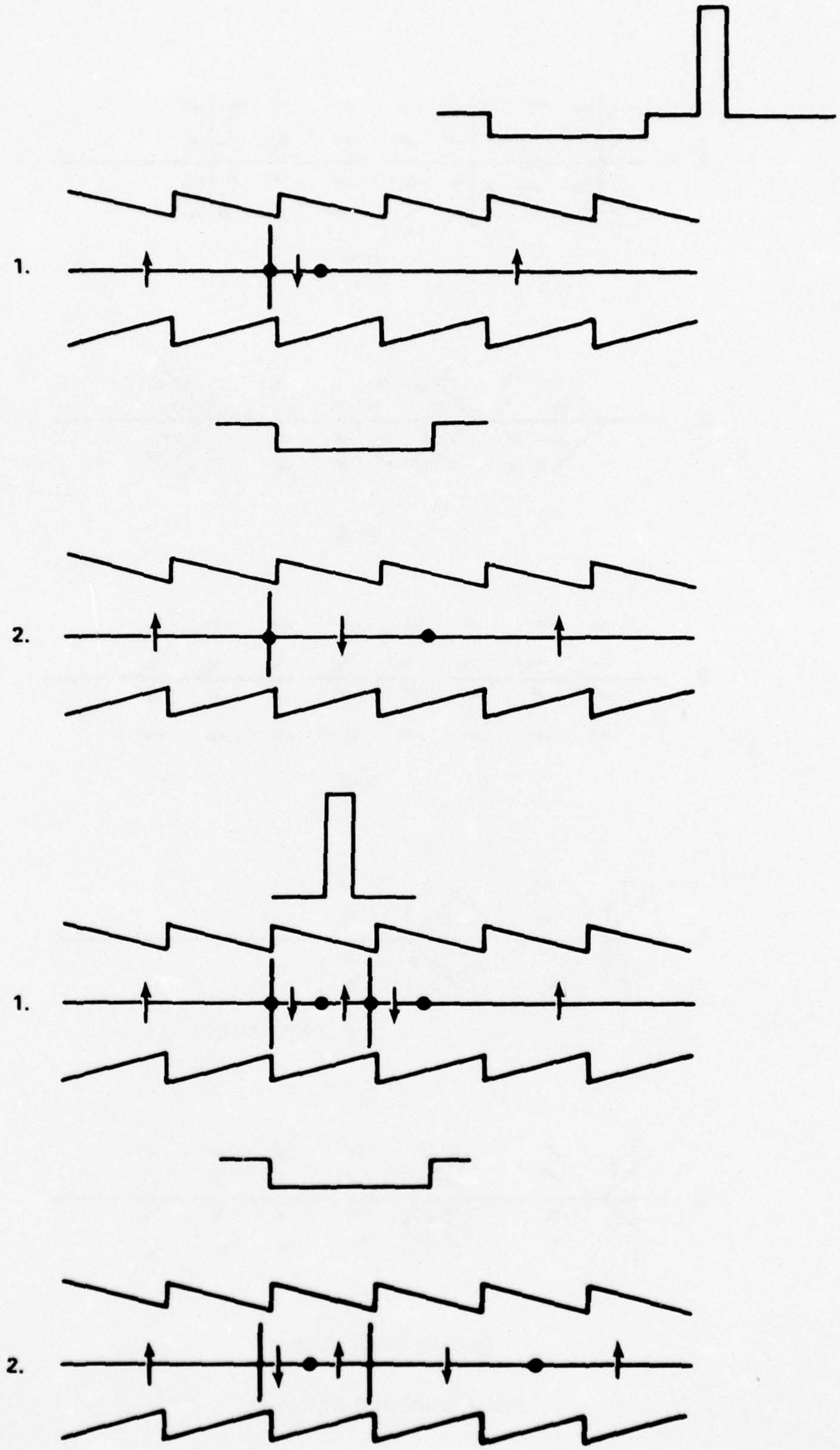


FIG. 6 CROSSTIE DUPLICATION

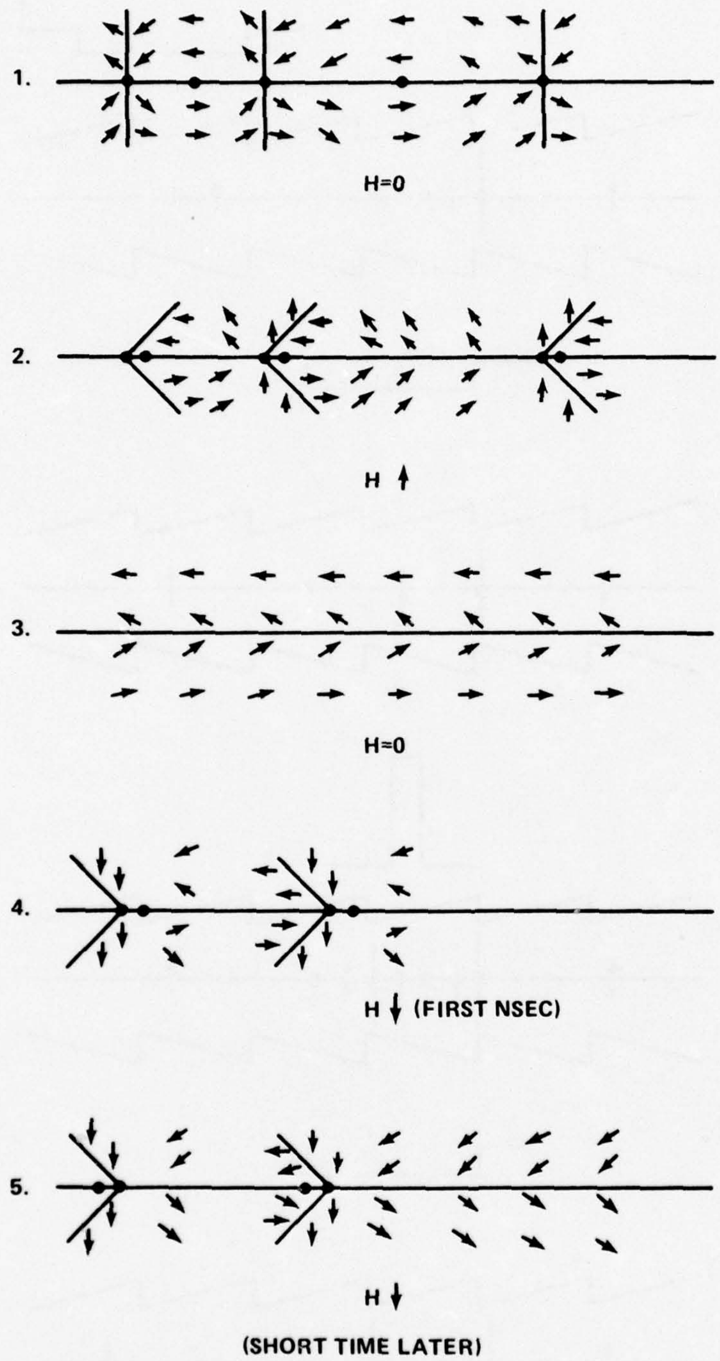


FIG. 7 CROSSTIE BENDING

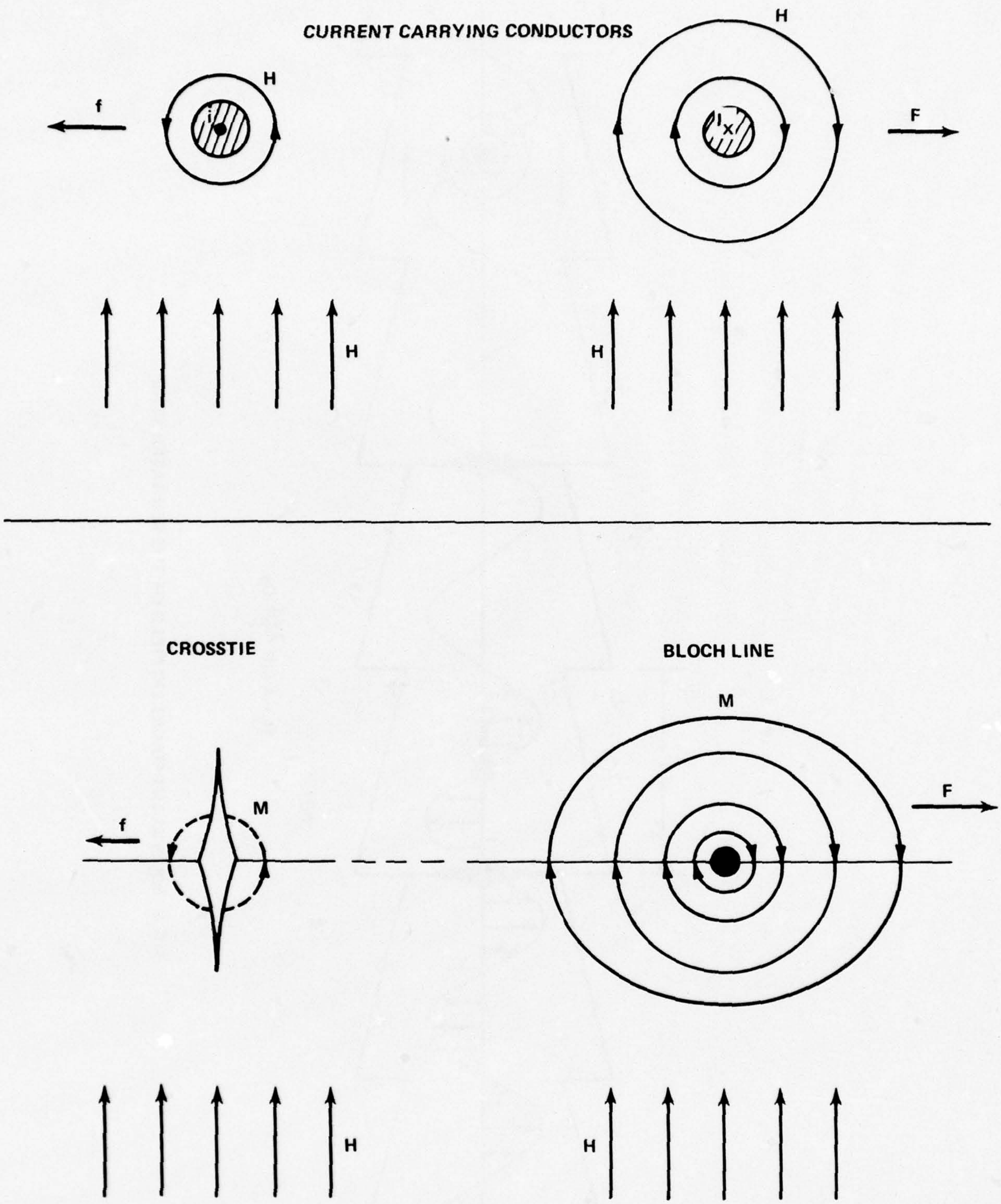
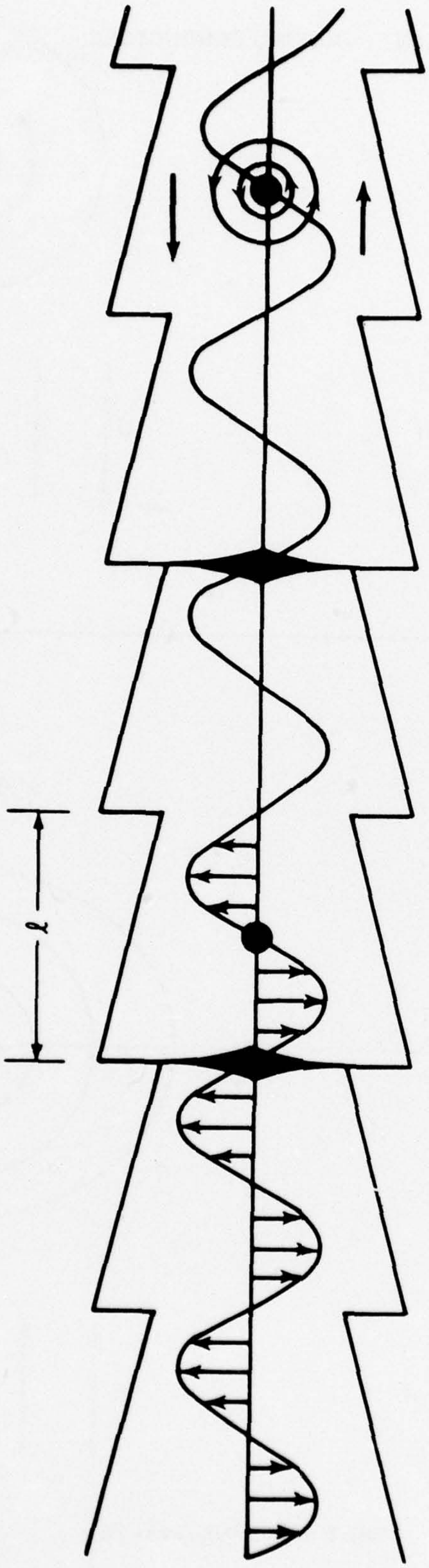


FIG. 8 A USEFUL ANALOGY



$H_s = -A \text{ SIN } \frac{2\pi X}{\ell}$ Oe

FIG. 9 EQUIVALENT MAGNETIC FIELD OF THE SERRATED STRIP

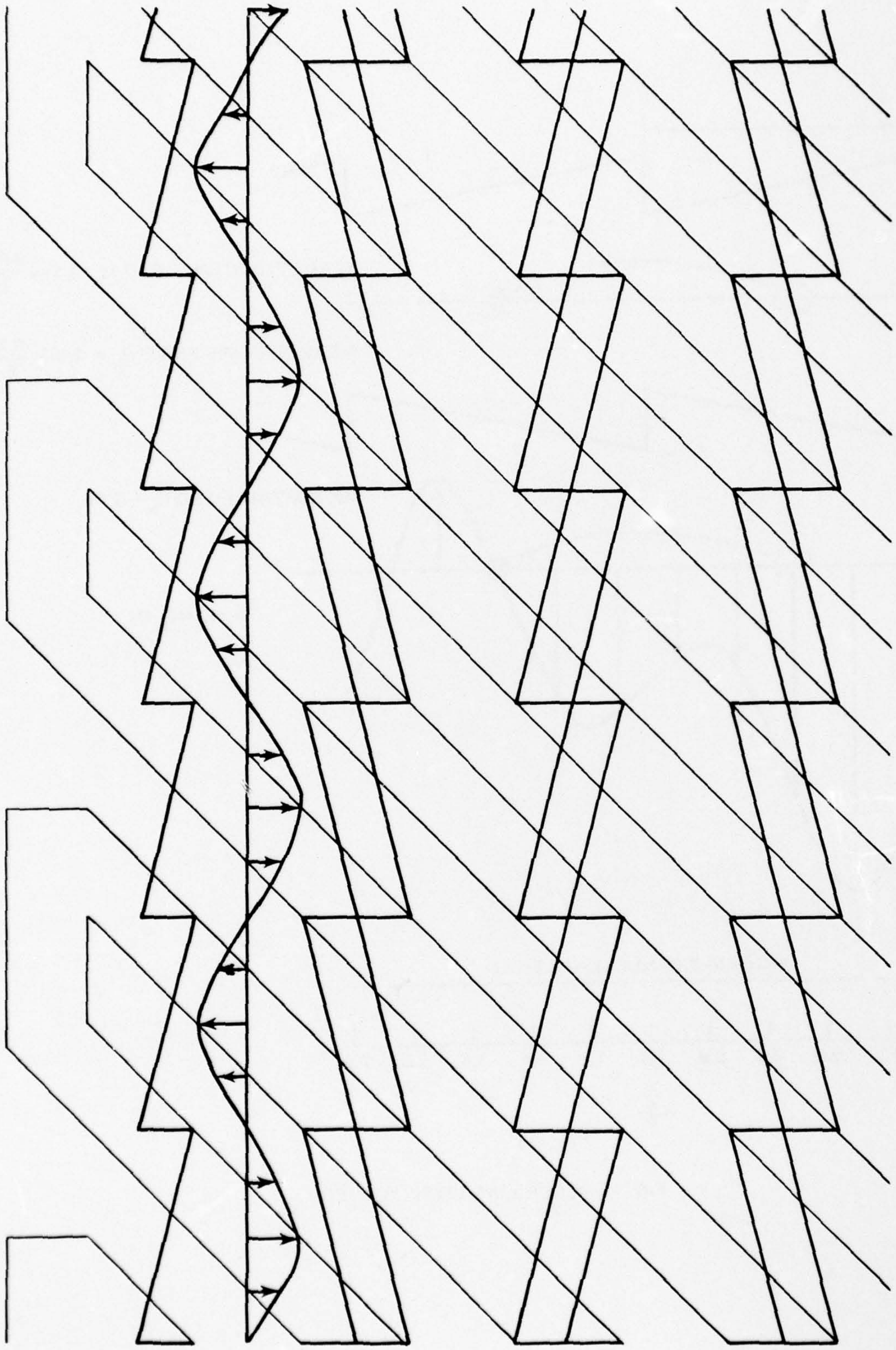


FIG. 10 MEANDER LINE AND VERTICAL FIELD COMPONENT

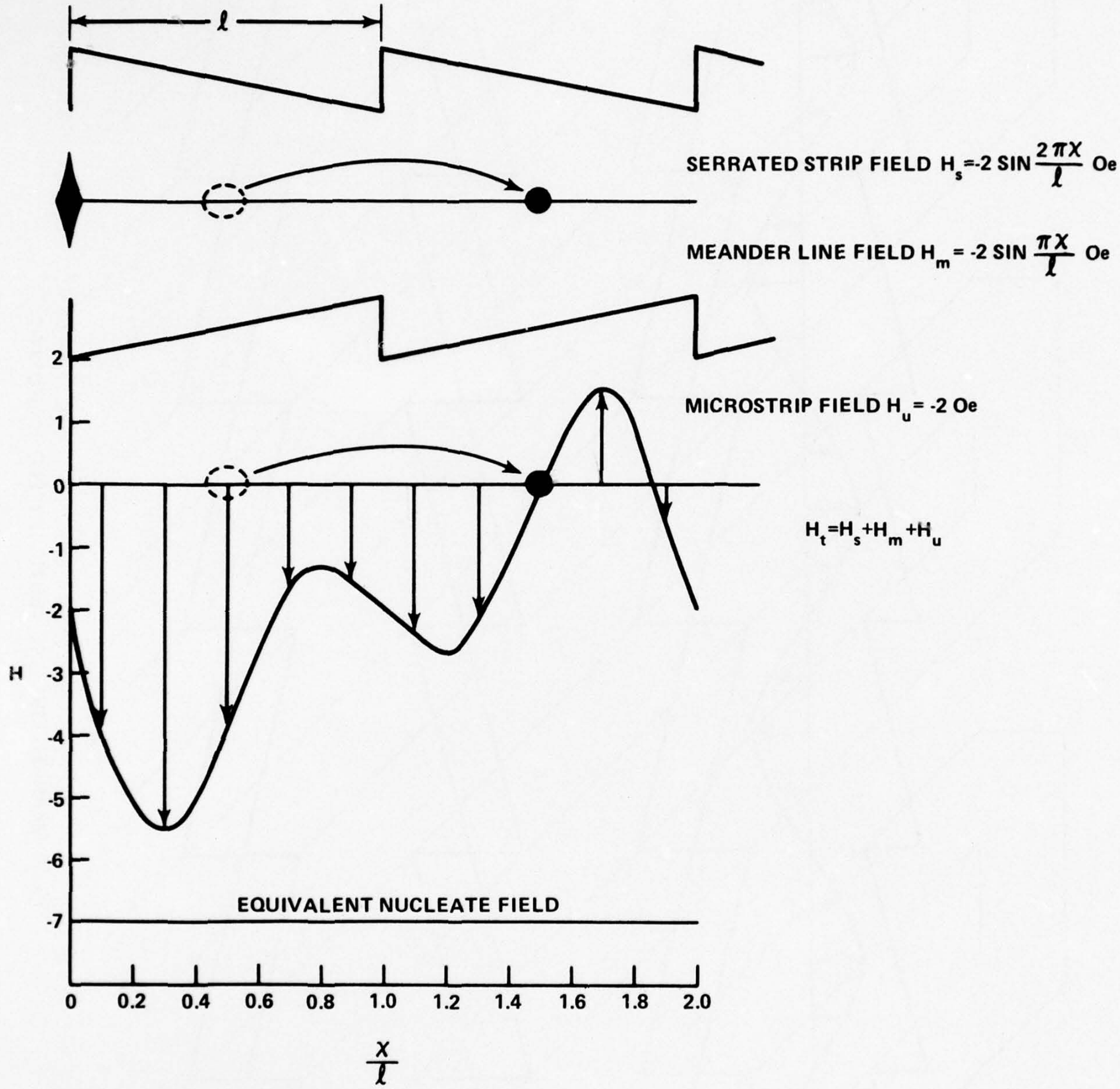


FIG. 11 BLOCH LINE STEPPING FIELD

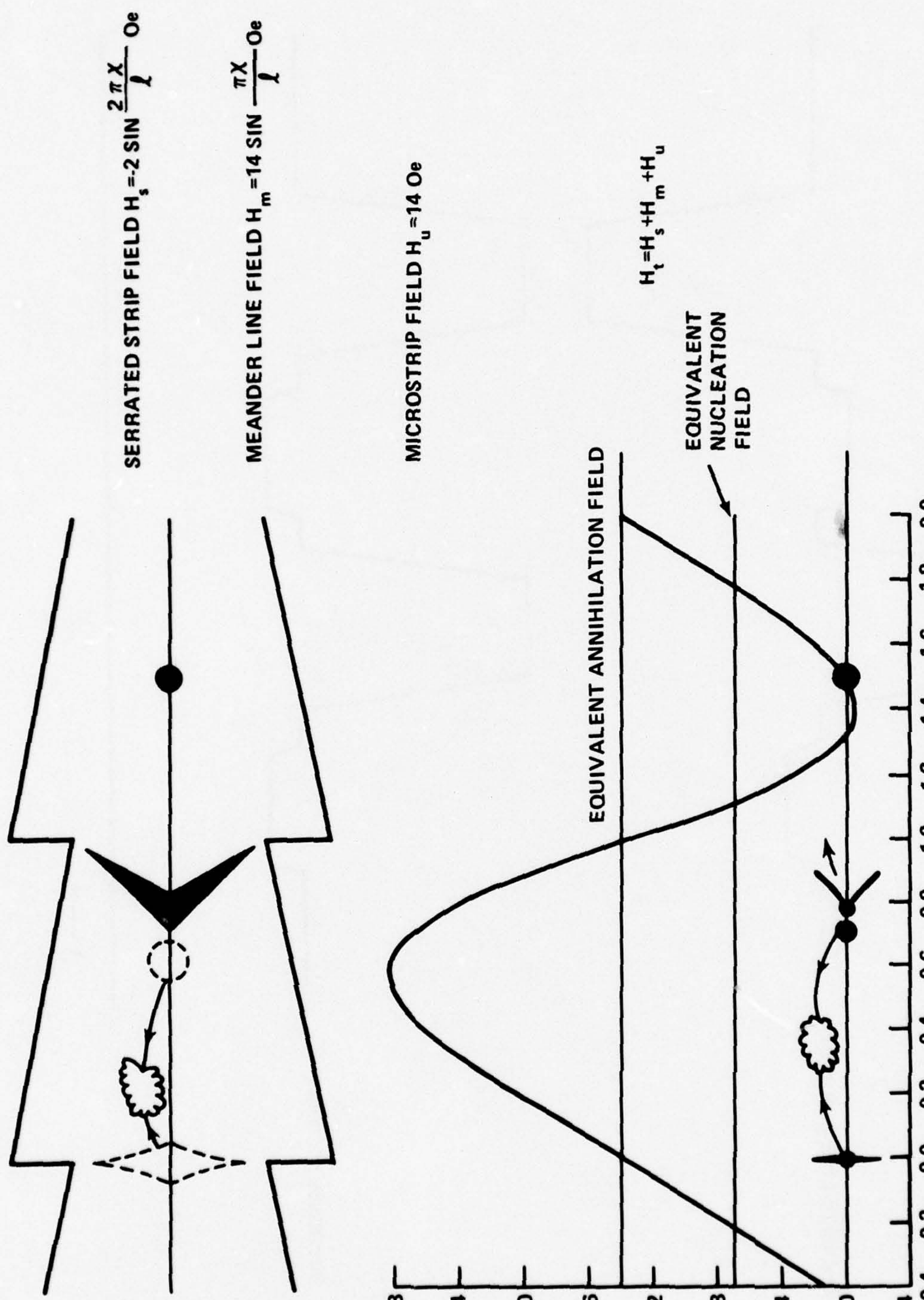


FIG. 12 CROSSTIE RELOCATION FIELD

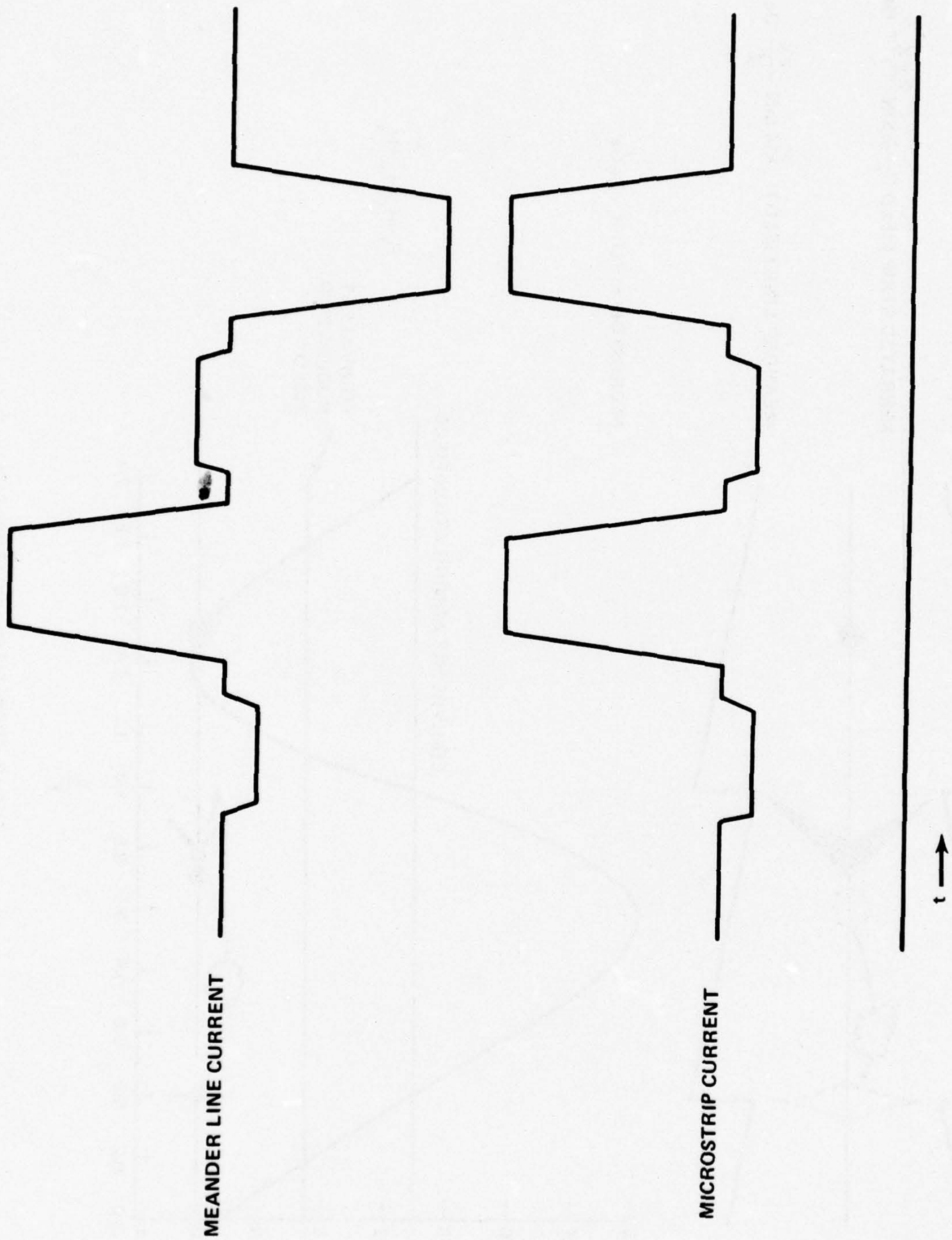


FIG. 13 PULSE SEQUENCE USING MEANDER LINE

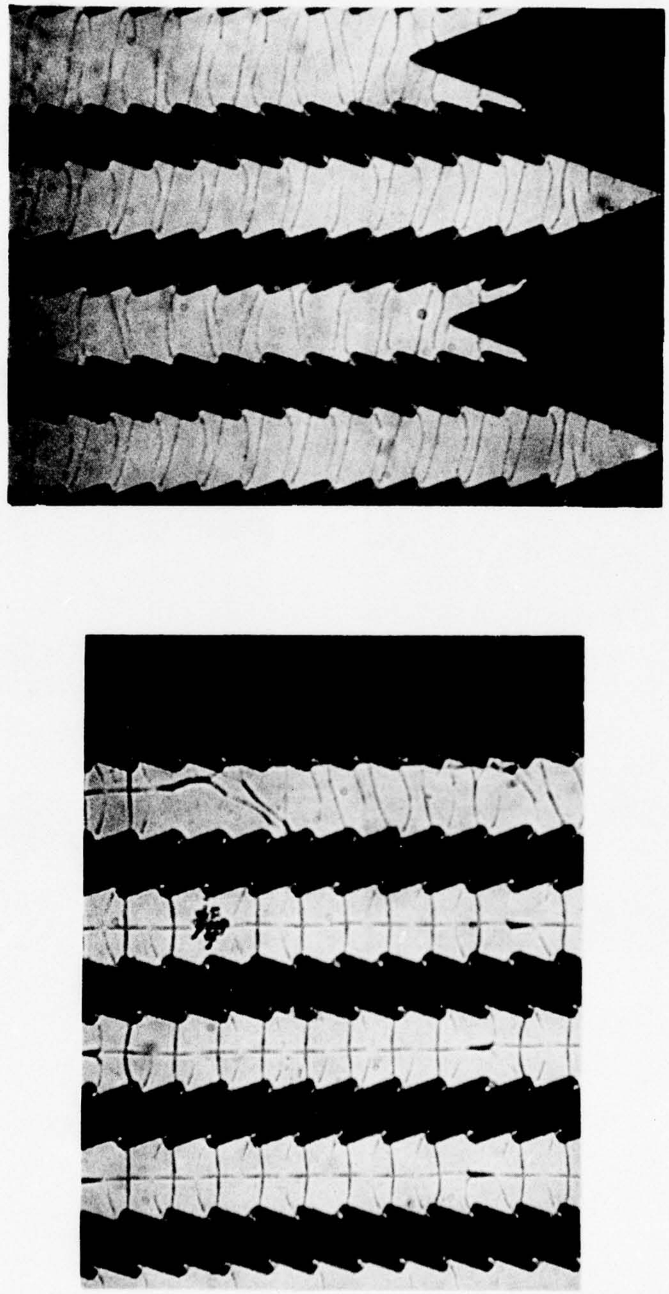


FIG. 14 SERRATED STRIPS PARALLEL TO HARD AXIS

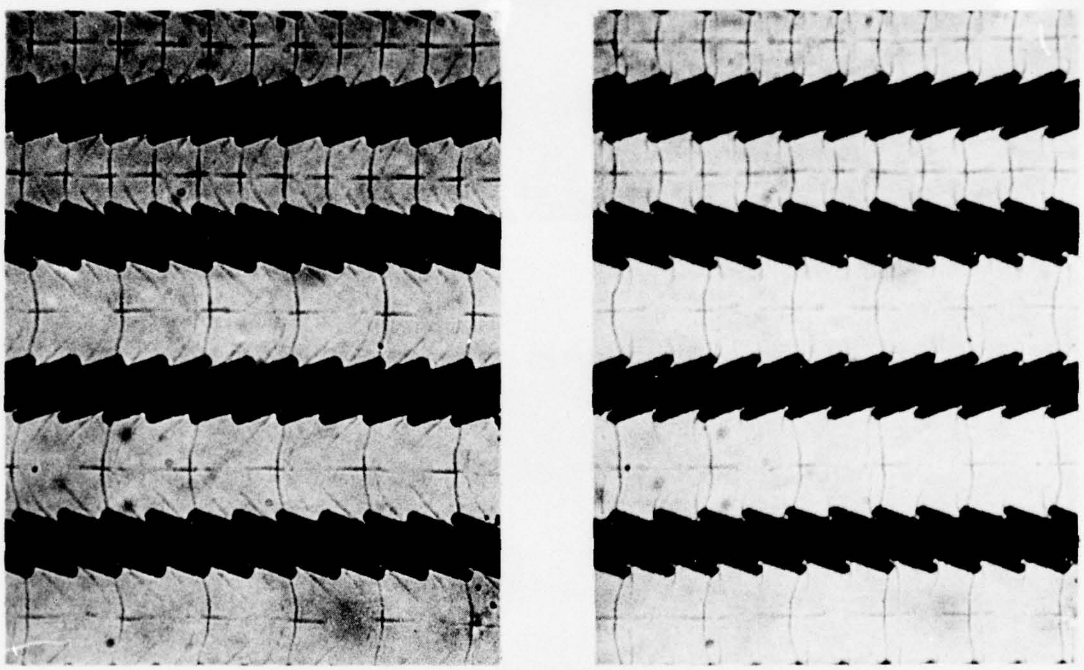


FIG. 15 CROSSTIE BENDING IN STRIPS ALONG HARD AXIS

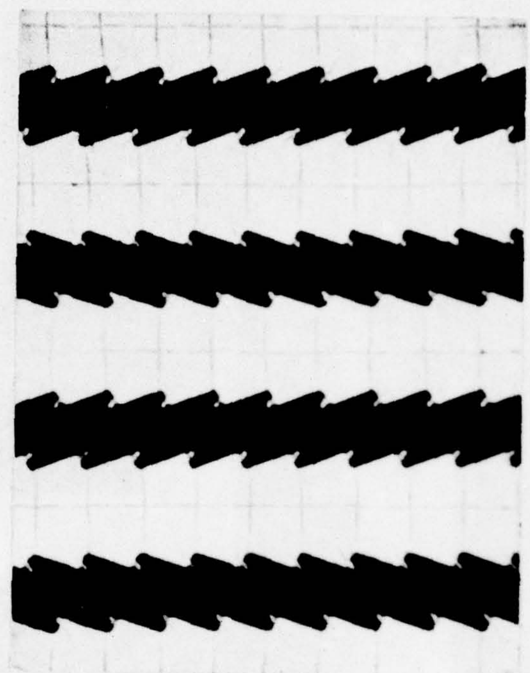


FIG. 16 SERRATED STRIPS OF ISOTROPIC FILM

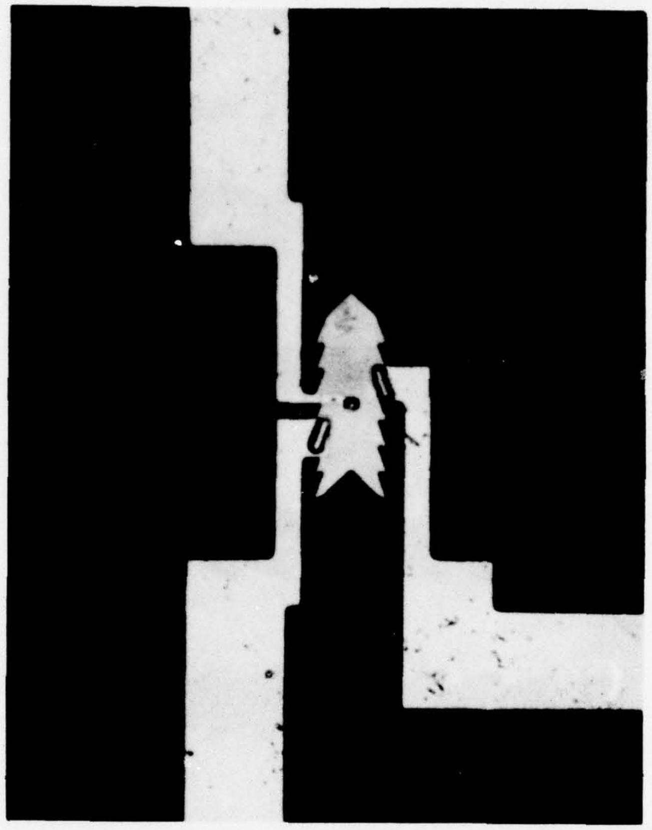


FIG. 17 DETECTOR ON SHORT SERRATED STRIP

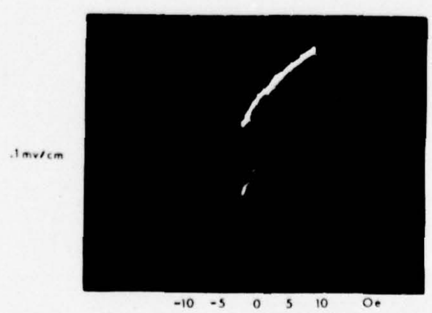


FIG. 18 DETECTOR OUTPUT RESULTING FROM ALTERNATING FIELD

DISTRIBUTION

	Copies
Director, Advanced Research Projects Agency	
1400 Wilson Blvd.	
Arlington, VA 22209	
Attn: Technical Library	3
Attn: Dr. G. H. Heilmeier	1
Advisory Group on Electron Devices	
201 Varick Street, 9th Floor	
New York, NY 10014	
Attn: Secretary	3
Air Force Avionics Laboratory	
Wright-Patterson Air Force Base, OH 45433	
Attn: Mr. Stan Wagner, AFAL/TEA	1
Mr. R. M. Werner, AFAL/TEA	1
Dr. M. G. Mier, AFAL/TEA-3	1
D. Brewer	1
Technical Library	1
Air Force Cambridge Research Laboratory	1
L. G. Hanscom Field	
Bedford, MA 01730	
Air Force Materials Laboratory	
Wright-Patterson Air Force Base, OH 45433	
Attn: Mr. Gene Miller, AFML/LTE	1
Dr. John DeCuire	1
Air Force Office of Scientific Research	1
Department of the Air Force	
Washington, DC 20333	
Air Force Weapons Laboratory	
Kirtland Air Force Base	
Albuquerque, NM 87117	
Attn: Technical Library	1
American Micro-Systems, Inc.	1
3800 Homestead Rd.	
Santa Clara, CA 95051	

DISTRIBUTION Cont.

	Copies
Ampex Corp. 401 Broadway Redwood City, CA 94063 Attn: H. A. Ferrier	1
Director, U.S. Army Engineering Research & Development Laboratories Fort Belvoir, VA 22060 Attn: Technical Documents Center	1
U.S. Army Research Office Box CM, Duke Station Durham, NC 27706	2
Autonetics Division North American Rockwell Corp. P.O. Box 4173 3370 Miraloma Ave. Anaheim, CA 92803 Attn: Dr. G. Pulliam	1
Bacco Industries 10350 Bacco Street South El Monte, CA 91733 Attn: Dr. Dean Palmer	1
Bell Telephone Laboratories, Inc. 600 Mountain Ave. Murray Hill, NJ 07971 Attn: Dr. A. H. Bobeck	1
Mr. W. Boyle	1
Bell Telephone Laboratories, Inc. Whippany Road Whippany, NJ 07981 Attn: Technical Reports Center (Rm. 2A-160)	1
The Boeing Co. Aerospace Division Seattle, WA 98124 Attn: Mr. James M. Bartlemay	1
The Boeing Co. P.O. Box 3999 Seattle, WA 98124 Attn: Mr. D. D. Robinson, Mail Stop 88-43	1

DISTRIBUTION Cont.

	Copies
The Bunker-Ramo Corp. 8433 Fallbrook Ave. Canoga Park, CA 91304 Attn: Howard L. Parks	1
Burroughs Corp. 5411 North Lindero Canyon Rd. Westlake Village, CA 91361 Attn: Dr. L. W. Brownlow	1
Burroughs Corp. Defense, Space & Special Systems Group Central Ave. Paoli, PA 19301 Attn: Mr. Robert L. Davis	1
University of California Department of Engineering Los Angeles, CA 90024 Attn: Dr. G. Estrin	1
Colorado State University Department of Physics Fort Collins, CO 80521 Attn: Dr. C. E. Patton	1
Components Corp. Denville, NJ 07834 Attn: Jerry B. Minter	1
Conrac Corp. P. O. Box 32 Caldwell, NJ 07006 Attn: Mr. John Lawton, Jr.	1
Central Intelligence Agency McLean, VA 22101 Attn: Dr. Pat Mechan	1
Control Data Corp. 5272 River Road Washington, DC 20016 Attn: Mr. W. E. Babcock	1
Cornell University School of Electrical Engineering Phillips Hall Ithaca, NY 14850 Attn: J. Frey	1

DISTRIBUTION Cont.

	Copies
Corning Glass Works Technical Information Center Sullivan Park Corning, NY 14830 Attn: R. R. Barber	1
Defense Documentation Center Cameron Station Alexandria, VA 22314	12
Office of the Director of Defense Research & Engineering Washington, DC 20301 Attn: Dr. L. Weisberg	1
Attn: Information Office Library Branch	3
Delco Electronics, Division of General Motors 7927 S. Howell Ave. Oak Creek, WI 53154 Attn: Technical Library	1
Fairchild Semiconductor Research & Development Laboratory 4001 Junipero Sierra Blvd. Palo Alto, CA 94304 Attn: J. M. Early	1
Wendell B. Sander	1
Dr. H. Sello	1
Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20553 Attn: Chief, Data Processing Branch	1
University of Florida Electrical Engineering Department Gainesville, FL 32601 Attn: Prof. J. K. Watson	1
General Electric Co. Electronics Park Syracuse, NY 13201 Attn: Mr. R. J. Clark	1
General Electric Co. Mail Drop 211 French Road Utica, NY 13502 Attn: R. C. May	1

DISTRIBUTION Cont.

	Copies
Grumman Aerospace Corp. Bethpage, NY 11714 Attn: R. Hong	1
USAECOM Fort Monmouth, NY 07703 Attn: Mr. David Harratz	1
Harris Semiconductor P. O. Box 883 Melbourne, FL 32901 Attn: Mr. A. L. Rivoli	1
Mr. Ron Neal	1
Harry Diamond Laboratories Washington, DC 20438 Attn: Branch 920 (Mr. A. J. Baba)	1
Technical Library	1
Honeywell, Inc. Aerospace Division 13350 U.S. 19 St. Petersburg, FL 33733 Attn: Thomas Crutcher	1
Honeywell, Inc. Systems & Research Center Research Dept. Roseville, MN 55113 Attn: Dr. Dale Gunderson	1
Dr. O. S. Lutes	1
Hughes Aircraft Co. Data Systems Div. Culver City, CA 90230 Attn: Dr. D. Calhoun	1
Hughes Aircraft Co. 500 Superior Ave. Newport Beach, CA 92660 Attn: Mr. George Wolfe, Jr.	1
Hughes Research Laboratory 3011 Malibu Canyon Rd. Malibu, CA 90265 Attn: Dr. G. Brewer	1

DISTRIBUTION Cont.

	Copies
IBM Corp. 18100 Frederick Pike Gaithersburg, MD 20760 Attn: Technical Library	1
IBM Corp. 150 Sparkman Drive Huntsville, AL 25805 Attn: Technical Library	1
University of Illinois Digital Computer Laboratory Urbana, IL 61801 Attn: Dr. W. J. Poppelbaum	1
Iowa State University Electrical/Ceramics Engineering Dept. Ames, IA 50010 Attn: T. A. Smay	1
Intel Corp. 365 Middlefield Rd. P. O. Box 668 Mountain View, CA 94040 Attn: Dr. G. Moore	1
Intelligence & Electronic Warfare Laboratory Rome Air Development Center Griffis Air Force Base Rome, NY 13442 Attn: Mr. James Previte	1
International Business Machines Corp. Owego, NY 13827 Attn: Mr. C. McNeil, Federal Systems Div., Electronic Systems Center	1
Mr. L. C. Liebschutz, 101BL03	1
International Business Machines Corp. Federal Systems Div. 1120 Connecticut Ave., N.W. Washington, DC 20036 Attn: E. S. Hopkins	1
ITT Avionics Division 500 Washington Ave. Nutley, NJ 07110 Attn: Dept 64511 (Mr. F. L. Koved)	1

DISTRIBUTION Cont.

	Copies
ITT Research Institute 10 West 35th Street Chicago, IL 60616 Attn: Harold A. Lauffenburger	1
The Johns Hopkins University Applied Physics Laboratory Johns Hopkins Rd. Laurel, MD 20810 Attn: Dr. C. Feldman	1
Lawrence Radiation Laboratory P. O. Box 808 Livermore, CA 94550 Attn: Technical Information Dept., L-3	1
Dr. K. Aaland, Code 154	1
Dr. I. Fischer-Colbie, Mail Stop 156	1
Litton Data System Van Nuys, CA 91400 Attn: Dr. John Klocka	1
Litton Systems, Inc. Guidance and Control Systems Division 5500 Canoga Ave. Woodland Hills, CA 91364 Attn: Dr. H. Abbink, M.S. 5330	1
Mr. J. Birdsall	1
Lockheed Missiles and Space Co. Dept 81-42, Bldg 531 P. O. Box 504 Sunnyvale, CA 94088 Attn: Mr. W. L. Morrison	1
The Magnavox Co. Bueter Rd. Fort Wayne, IN 46803 Attn: M. E. Seif	1
Commandant, Marine Corps Scientific Advisor (Code AX) Washington, DC 20380	1

DISTRIBUTION Cont.

	Copies
Massachusetts Institute of Technology Department of Aeronautics and Astronautics 68 Albany Street Cambridge, MA 02139 Attn: Mr. G. Ives	1
McDonnell Douglas Corp. P. O. Box 516 St. Louis, MO 63166 Attn: Mr. Kent C. Smith	1
University of Michigan Logic and Computers Group 611 Church Street Ann Arbor, MI 48104	1
Department of Electrical Engineering University of Minnesota Minneapolis, NM 55455 Attn: Larry L. Kinney	1
Prof. J. Judy	1
The Mitre Corp. Bedford, MA 01730 Attn. Library	1
Montana State University Electrical Engineering Department Bozeman, MT 59715 Attn: D. Rudberg	1
Motorola Incorporated Semiconductor Projects Division 2200 West Broadway Box 20906, Mail Station M504 Phoenix, AZ 85036 Attn: John Osborne	1
NASA, Marshall Space Flight Center Huntsville, AL 35812	1
NASA Manned Space Flight Center Houston, TX 77058	1

DISTRIBUTION Cont.

	Copies
National Bureau of Standards Bldg 225, Rm A-331 Washington, DC 20234	
Attn: Mr. Leedy	1
Technical Library	1
Robert J. Warner	1
Dr. M. Bollis	1
Director, National Security Agency Fort George G. Meade, MD 20755	
Attn: TDL, Dianne Haslup	1
Commander, Naval Air Development Center Warminster, PA 18974	
Attn: Code AEHA (Mr. H. Naubriet)	1
Mr. R. Fedorak	1
Technical Library	1
Commander, Naval Air Systems Command Washington, DC 20360	
Attn: AIR-360 (F. Lueking)	1
AIR-360 (A. D. Klein)	1
AIR-50174	14
AIR-52022 (C. D. Caposell)	30
AIR-52022 (A. S. Glista)	1
AIR-310 (Dr. H. J. Mueller)	1
AIR-310B (J. W . Willis)	2
Naval Avionics Facility Indianapolis, IN 46218	
Attn: M. L. Gallagher, Librarian	1
Mr. Dale Tague	1
Commander, Naval Electronics Laboratory Center San Diego, CA 92152	
Attn: Code 4800	1
Mr. J. Zymanski, Code 3200	1
Research Laboratory	1
Commander, Naval Electronics Systems Command Washington, DC 20360	
Attn: Code ELEX-05143 (C. R. Suman)	1
Code 033 (N. Butler/L. Sumney)	1
Naval Explosive Ordnance Disposal Facility Indian Head, MD 20640	
Attn: Technical Library	1

DISTRIBUTION Cont.

	Copies
Naval Missile Center Point Mugu, CA 93010 Attn: Technical Library (Code 5632.2)	1
Naval Oceanographic Office Suitland, MD 20373 Attn: Technical Library (Code 1640)	1
Deputy Chief of Naval Operations (Development) Technical Analysis and Advisory Group (Code NOP-077D) Washington, DC 20350	1
Commander, Naval Sea Systems Command Washington, DC 20360 Attn: SEA-031	1
Naval Ordnance Station Louisville, KY 40214 Attn: Technical Library	1
Naval Ordnance Station Indian Head, MD 20640 Attn: Technical Library	1
Naval Postgraduate School Monterey, CA 93940 Attn: Technical Library (Code 0212)	1
Director, Naval Research Laboratory Washington, DC 20390 Attn: Mr. George Abraham	1
Technical Library	3
Dr. D. O. Patterson	1
Dr. A. Brodzinsky	1
Mr. H. Lessoff	1
Dr. M. Rubenstein	1
Dr. F. Milton	1
Dr. Conrad M. Williams (Code 6411)	1
Office of Naval Research 800 North Quincy Street Arlington, VA 22217 Attn: Dr. L. E. Larmore, Code 201	1
Dr. T. G. Berlincourt, Code 420	1
Dr. J. Trimble	3

DISTRIBUTION Cont.

	Copies
Commanding Officer Office of Naval Research Branch Office 495 Summer Street Boston, MA 02210	3
Commanding Officer Office of Naval Research Branch Office 536 South Clark Street Chicago, IL 60605	3
New York Area Office Office of Naval Research 207 West 24th St. New York, NY 10011	3
Commanding Officer Office of Naval Research Branch Office 1030 East Green St. Pasadena, CA 91101	3
San Francisco Area Office Office of Naval Research 760 Market St., Rm 447 San Francisco, CA 94102	3
Naval Research Laboratory Underwater Sound Reference Division P. O. Box 8337 Orlando, FL 32806 Attn: Technical Library	1
Naval Ship Engineering Center Philadelphia Division Philadelphia, PA 19112 Attn: Technical Library	1
Naval Ship Research and Development Center Washington, DC 20007 Attn: Central Library (Code L42 and L43)	1
Naval Underwater Systems Center Newport, RI 02840 Attn: Robert Kieronski, SB-13	1
Naval Training Equipment Center Orlando, FL 32813 Attn: Technical Library	1

DISTRIBUTION Cont.

	Copies
Naval Undersea Warfare Center 3202 East Foothill Blvd. Pasadena, CA 91107 Attn: Technical Library	1
Navy Underwater Sound Laboratory Fort Trumbull New London, CT 06320 Attn: Technical Library	1
Commander, Naval Weapons Center China Lake, CA 93557 Attn: Dr. W. Webster	1
Technical Library	1
Digital Development Corporation P. O. Box 23447, San Diego, CA 92123 Attn: Dr. Ben Meckel, Sr. Staff Phys.	1
Northrop Electronics Division 2301 West 120th St. Hawthorne, CA 90250 Attn: Mr. M. Jasper	1
North American Rockwell P. O. Box 4192 3370 Miraloma Ave. Anaheim, CA 92803 Attn: W. H. Kraemer	1
North American Rockwell Microelectronics Company P. O. Box 3669 3430 Miraloma Ave. Anaheim, CA 92803 Attn: R. W. Downing	1
Raytheon Company Missile Systems Division Bedford, MA 01730 Attn: Dr. R. E. Thun	1
Navy Space Systems Activity P. O. Box 92960 Worldway Postal Center Los Angeles, CA 90009 Attn: Dr. J. L. Finkelstein	1

DISTRIBUTION Cont.

	Copies
RCA, Astro-Electronics Division P. O. Box 800 Princeton, NJ 08520 Attn: Maurice G. Staton	1
RCA, David Sarnoff Research Center Princeton, NJ 08540 Attn: Mr. H. H. Scott, Jr.	1
RCA, Defense Electronic Products Route 202 Somerville, NJ 08876 Attn: Dr. Pan	1
RCA Laboratories Princeton, NJ 08540 Attn: Dr. R. Shahbender	1
USAMICOM Huntsville, AL 35809 Attn: Mr. Dan Reed	1
Rome Air Development Center Griffis Air Force Base, NY 13440 Attn: Mr. J. Brauer	1
Safeguard Systems Office 1320 Wilson Blvd. Arlington, VA 22209 Attn: Dr. Richard Merwin	1
Sanders Associates, Inc. 95 Canal St. Nashua, NH 03060 Attn: D. B. Newman	1
Sandia Laboratories P. O. Box 5800 Albuquerque, NM 87115 Attn: Tech Library 3141	1
Signetics Corp. 811 E. Arques Ave. Sunnyvale, CA 94086	1
Siliconix, Inc. 2201 Laurelwood Santa Clara, CA 95054	1

DISTRIBUTION Cont.

	Copies
Singer-General Precision, Inc. Kearfott Division 1150 McBride Ave. Little Falls, NJ 07424 Attn: Mr. L. Laermer	1
Sperry Rand Corp. Sperry Rand Research Center Sudbury, MA 01776 Attn: Mr. H. A. Richard Wegener	1
Stanford Research Institute Engineering Sciences Laboratory Menlo Park, CA 94025 Attn: Louis N. Heynick	1
Dr. S. W. Miller, Bldg 30	1
Strategic Systems Project Office Department of the Navy Washington, DC 20360 Attn: Code SP-23 (Mr. David Gold)	1
Teledyne Systems Co. 19601 Nordhoff St. Northridge, CA 91324 Attn: Earl Kanter	1
Texas Instruments Inc. P. O. Box 5012 Dallas, TX 75222 Attn: Dr. Bernard G. Carbajal	1
Dr. Dean Tombs	1
Texas Instruments Inc. P. O. Box 66027 Houston, TX 77006 Attn: Bob R. Evans, MS-649	1
TRW Systems, Inc. One Space Park Redondo Beach, CA 90278 Attn: Dr. B. Dunbridge	1
Texas Instruments Laboratories Central Research P. O. Box 5936 Dallas, TX 75222 Attn: Dr. John M. Pankrate, M.S. 105	1

DISTRIBUTION Cont.

	Copies
Tyco Laboratories, Inc. 16 Hickory Bear Hill, Waltham, MA 02154 Attn: Dr. A. I. Mlavsky	1
United Aircraft Corp. United Aircraft Research Laboratories East Hartford, CT 06108 Attn: Dr. A. J. Demarla	1
UNIVAC Federal Systems Division Univac Park P. O. Box 3525 St. Paul, MN 55101 Attn: Dr. D. Lo, M.S. 5161	5
Mr. W. D. Miller	1
Westinghouse Electric Corp. Aerospace Division Friendship International Airport P. O. Box 746 Baltimore, MD 21203 Attn: Dr. Paul M. Pan	1
Ms. L. Campbell	1
Western Electric Corp. Defense Activities Division 83 Maiden Lane New York, NY 10038 Attn: Information Center (4th Floor)	1
Westinghouse Electric Corp. Westinghouse Research Laboratory Bulah Road, Churchill Borough Pittsburgh, PA 15235 Attn: Dr. D. Muss	1
Yale University Becton Center 15 Prospect Street New Haven, CT 06520 Attn: Prof. R. Alben	1
Prof. R. C. Barker	1
Prof. S. Gargill	1

DISTRIBUTION Cont.

	Copies
Youngstown State University 410 Wick Avenue Youngstown, OH 44503 Attn: Dr. M. Simon	1
IBM Corporation Moneterey & Cottle Roads San Jose, California 95193 Attn: G. R. Henry, P35/025	1
NTIS Dept. of Commerce Springfield, VA 22161 Attn: Dr. George Kudrovatz	1
Control Data Corporation, Research Division P. O. Box 1249 Minneapolis, MN 55440 Attn: Gale R. Allen, HOM291	1
Raytheon Research Division Waltham, MA 02154 Attn: Dr. E. Schlomann	1
Dr. Seavey	1
AMF Sea Link 1025 N. Royal St. Alexandria, VA 22314 Attn: Don Heckman	1
Stanford University 110 McCullogh Bldg. Stanford, CA 94305 Attn: Prof. Robert L. White	1
Honeywell Information Systems Inc. Advanced Systems & Technology 4000 N.W. 39th St., Bldg. 1, Room 53 Oklahoma City, OK 73112 Attn: Dr. W. Kayser	1
Westinghouse Advanced Technology Lab P. O. Box 1521 Baltimore, MD 21203 Attn: Dr. D. Mergerion, MS 3714	1

DISTRIBUTION Cont.

	Copies
NCR Corporation Advance Development Engineering Box 728 Cambridge, OH 43725 Atn: Mark Tkacik	1
Hewlett - Packard 1920 Embarcadero Road Palo Alto, CA 94303 Attn: Dr. Paul Greene	1
Navy Space Systems Activity P. O. Box 92960 Worldway Postal Center Los Angeles, CA 90009 Attn: Jay L. Finkelstein	1
Chief Naval Material Command Washington, D.C. 20360 Attn: NMAT 0343	1
Tektronix, Inc. P. O. Box 500 Beaverton, OR 97077 Attn: Director of Research	1

NDW-NSWC(W)-5605/1 (Rev. 1-75)

TO AID IN UPDATING THE DISTRIBUTION LIST FOR NAVAL SURFACE WEAPONS CENTER, WHITE OAK LABORATORY TECHNICAL REPORTS PLEASE COMPLETE THE FORM BELOW:

TO ALL HOLDERS OF NSWC/WOL/TR 77-21

by L. J. Schwee, Code WR-34

DO NOT RETURN THIS FORM IF ALL INFORMATION IS CURRENT

A. FACILITY NAME AND ADDRESS *(OLD) (Show Zip Code)*

NEW ADDRESS *(Show Zip Code)*

B. ATTENTION LINE ADDRESSES:

C.

☐ REMOVE THIS FACILITY FROM THE DISTRIBUTION LIST FOR TECHNICAL REPORTS ON THIS SUBJECT.

D.

NUMBER OF COPIES DESIRED ______________________

GPO 888-970

DEPARTMENT OF THE NAVY
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MD. 20910

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
DEPARTMENT OF THE NAVY
DOD 316

COMMANDER
NAVAL SURFACE WEAPONS CENTER
WHITE OAK, SILVER SPRING, MARYLAND 20910

ATTENTION: CODE WR-34